Visualizing the Ergosphere from Supermassive Black Hole M87 shadow image taken by Event Horizon Telescope

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Abstract

Using a free image editing software, GIMP, by applying edge filters we show a possible real shape of the nearly region of the event horizon, what could actually be in contact with the ergosphere of M87 Supermassive Black Hole; images are in high quality from Event Horizon Telescope Collaboration on april 11th 2019 papers.

Introduction

Visualizing the Ergosphere from a Black Hole shadow is a highly speculative job. However, guide by some theoretical knowledges we can approach to what we in fact are seeing.

The ergosphere is a region located outside a rotating black hole's outer event horizon. Its name was proposed by Remo Ruffini and John Archibald Wheeler during the Les Houches lectures in 1971 and is derived from the Greek word ergon, which means ”work”. It received this name because it is theoretically possible to extract energy and mass from this region. The ergosphere touches the event horizon at the poles of a rotating black hole and extends to a greater radius at the equator.

Its frontier is given by Eq. 1:

$$r_s = \frac{GM}{c^2} - \frac{a^2}{c^2}\cos^2\theta \tag{1}$$

Figure 1: Arrow show actual border before applying two edge filters from Gimp, first one is Neon edge filter, and second one Laplace. As we can see its similar to a Kerr black hole shadow shape.

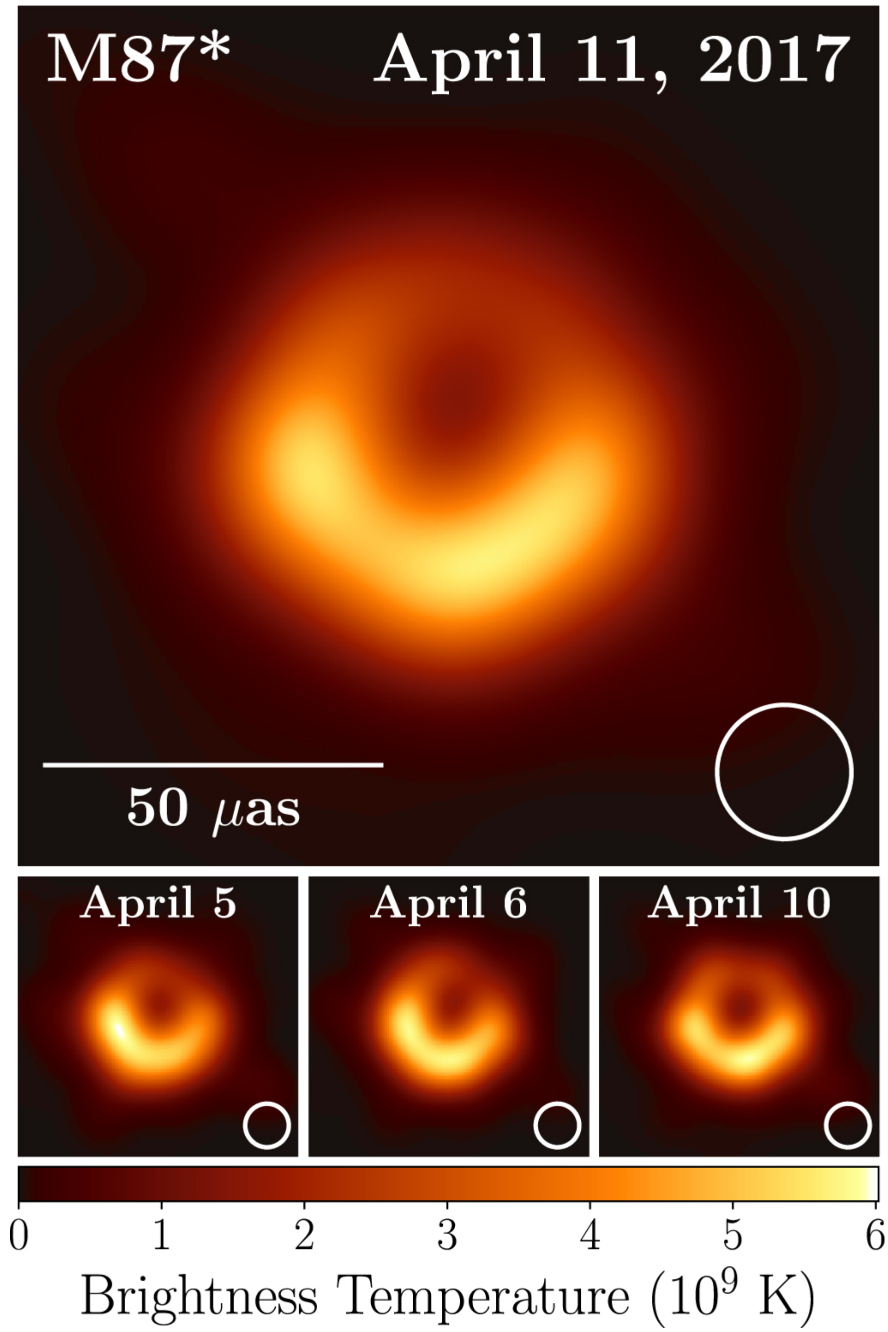

Figure 2: High quality Shadow of Supermassive Black Hole M87 by Event Horizon Telescope Collaboration. Here we can only see a diffuse shape, there is no obvious structures to identifiy.

The surface

The Kerr metric has two physical relevant surfaces on which it appears to be singular. The inner surface corresponds to an event horizon similar to that observed in the Schwarzschild metric; this occurs where the purely radial component g_{rr} of the metric goes to infinity.

Another singularity occurs where the purely temporal component g_{tt} of the metric changes sign from positive to negative.

Due to the $\cos^2\theta$ term in the square root, this outer surface resembles a flattened sphere that touches the inner surface at the poles of the rotation axis, where the colatitude θ equals 0 or π; the space between these two surfaces is called the ergosphere.

As we can see in figure 3 a rotation parameter $0.90 < \alpha < 0.99$, as in [1] was found $\alpha = 0.90 \pm 1$, corresponding to a rotational energy of about 10^{64} erg. Accordingly to the Kerr metric [2] and recently described in [3], this shadow is compatible with Kerr theory, and be in "contact" with the real Ergosphere external left border, as we can see in the schematic representation 4. This is why we could actually seeing part of the Ergosphere.

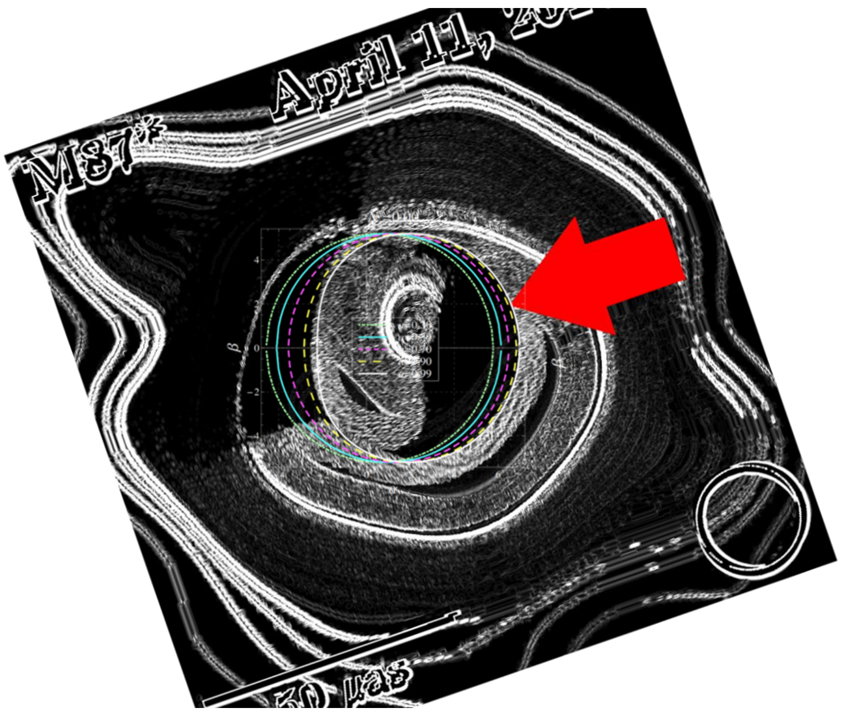

Figure 3: Compound Image of real black hole shadow and schematic representation of rotating Kerr black hole shadow in the absence of any surrounding field, where alpha is in between 0.99 and 0.90

Figure 4: Shadow (black) & horizons and ergospheres (white) of a rotating black hole. The dimensionless spin parameter a/M=Jc/G/M² is running from 0 to 1. Units: G=M=c=1 (lengths are in GM/c²). The observer is assumed to be far away from the black hole and stationary with respect to the fixed stars.

1 Conclusion

As so many physicists say: ”there is no way to direct observe the black hole event horizont”, but we can see at least a border that Ergosphere must be directly touching.

We finally present a way to rediscover the shadow of Supermassive Black Hole using simple and common-use imaging editing software.

References

[1] Massimo Della Valle Fabrizio Tamburini, Bo Thidé. Measurement of the spin of the M87 black hole from its observed twisted light. *arXiv*, apr 2019.

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[3] Yu-Xiao Liu Robert B. Mann Shao-Wen Wei, Yuan-Chuan Zou. Curvature radius and Kerr black hole shadow. *arXiv*, apr 2019.